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MEMBRANE STRETCH TESTING OF
LAMINATED CORRUGATED PHOENIXBOARD
FOR CORRUGATED PALLET

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DONG JUN LEE

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Major professor

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MEMBRANE STRETCH TESTING OF LAMINATED CORRUGATED AND PHOENIXBOARD FOR CORRUGATED PALLETS

By

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ABSTRACT

MEMBRANE STRETCH TESTING OF
LAMINATED CORRUGATED AND PHOENIX BOARD
FOR CORRUGATED PALLETS

By

Dong Jun Lee

The properties of Phoenixboard™ used for the top and bottom decks of corrugated pallets were investigated. Tests were conducted to compare the performance of Phoenix board to C-flute corrugated board for decks of paper-based pallets. Also, tests evaluating the material properties of the two materials were used to find the functionality. In order to find the needed properties, membrane stretch tests were conducted for the deflection analysis for the top deck of the corrugated pallet. The burst test, edge crush test, friction test, puncture test and moisture absorption test provided information for comparison of the two types of board.

The results showed that Phoenixboard™ can endure heavier loads than C-flute corrugated board. Also, the results reveal that Phoenixboard™'s performance can be ensured, without failure, up to a 1 inch load deflection. Despite this promising finding, other experimental data suggest that Phoenixboard™ should not be used for other parts of corrugated pallets such as legs. The ideal choice is to use Phoenixboard™ for top and bottom decks and corrugated board for pallet block.

The test method recommended by Stone Container has flaws that have been identified in this thesis.

This thesis is dedicated to my family and to my best friend, Anita.

ACKNOWLEDGMENTS

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Lastly, I would like to thank my parents, Juhan Lee and Suhee Lim, for their financial support throughout my program years and to whom I will always be grateful. I am especially thankful to Anita Lee, who offered emotional assistance for many years. And, I sincerely thank my friends and foes in America for making me strong.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1.0 INTRODUCTION

In the U.S pallet industry, about half of the pallets are one-way pallets and the other half are reusable. The problem is that eventually all pallets require disposal and replacement. The wooden pallet has a large market share and consumes much of the wood fiber produced. In the past, the easiest method of disposal for used pallets was landfilling, but this method is clearly not the most suitable. Restricted landfill space since the late 80's has been one of the most significant factors influencing pallet recycling. Pallet recycling is very labor intensive and has functioned with fewer standards and controls than new pallet construction (Pallet Enterprise, 1995).

In the late 70's and early 80's the grocery industry complained about wooden pallets. They expected more from their suppliers and more performance from their systems. The wooden pallet was not a valuable distribution system any longer. They were searching for alternative materials. Corrugated pallets offered great satisfaction on competitive single-trip product because a corrugated recycling system was already in place in the grocery industry. They are also clean and have no protruding fasteners (Pallet Enterprise, 1991).

The automotive industry simultaneously determined to replace wooden pallets. For example, General Motors (GM) introduced a new packaging policy about pallets. In an effort to be more "environmentally conscientious", GM required that all palletized shipments from suppliers under 500 pounds should be sent on paper based pallets to certain assembly plants. This was done under the program name "We Care" (Waste Elimination and Cost Awareness Rewards Everyone) (Ailsworth, 1995).

A number of companies are actively pursuing the design and manufacture of different forms of corrugated pallets. Corrugated pallets of various designs have common characteristics which are highly appealing. They are light- weight, much lighter than the wooden alternatives and recyclable. The industry pushes this concept effectively in their market efforts. The corrugated recycling stream is well established, particularly when compared to wood recycling. As a result, many corrugated pallets makers push the environmentally friendly property of their products when compared to wood.

Paper- based pallets are easily recycled since they are made from the original paper. Most paper- based pallets are not used for extra trips through the distribution cycle as compared to plastic or wooden pallets. Paper- based pallets are considered as one-way pallets. The companies who ship products on paper- based pallets do not expect the pallets to be returned to them. They expect the customers to add them to the paperboard recycling system.

Most corrugated pallets known to us are designed in beam strength fashion similar to standard wooden pallets that have long stringers to support the deck. This "Beam Strength" type is drawing strong interest in today's market because of this similarity (Pallet Enterprise, 1995).

Previous to the development of the innovative stringer concepts, most of the designs for corrugated paperboard pallets were of a block design constructed by using some form of blocks that supported the top sheet (usually with nine blocks). Many block concept pallets also have bottom sheets to help maintain the location and integrity of the blocks. This design concept continues to be common for a number of suppliers. Some large corrugated companies, such as the Stone Container Corporation, have developed a successful product line of block-style corrugated pallets. Their patented Cordeck™ design has gained solid acceptance for light loads in the automotive industry (Pallet Enterprise, 1995).

Cordeck pallets are specifically designed to meet the demands of application. The Stone Container Company currently manufactures over 500 different styles and sizes. Cordeck pallets have been widely used in the automotive industry in the last few years to ship unit loads of 500 pounds or less from parts suppliers to assembly plants. They are manufactured with partially or completely recycled material. A typical Cordeck pallet weighs only about 12 pounds (Pallet Enterprise, 1995). Recently, a substitute material for the top and bottom of the Cordeck was developed by Fortifiber Corporation. This material is called Phoenixboard™ and made with 100 % recycled materials. This material was tested and analyzed for use as pallet decks.

The corrugated pallets have some distinct problems. It is quite difficult to design corrugated pallets to have the strength for many unit load applications, particularly when it comes to racking requirements. Exposure to moisture can seriously degrade the strength of corrugated board, although there are some coatings that help alleviate the problem. Direct exposure to precipitation is obviously bad, but even high humidity can severely damage many corrugated pallets (Pallet Enterprise, 1995).

A study conducted by Ailsworth (1995) investigated the "compression and dynamic testing of paper corrugated pallets at standard and high humidity climates". It was seen that the maximum permanent compression set in any corrugated pallet was 0.375 inches. The damage that the pallets suffered was only cosmetic for all the pallets tested under high temperature and humidity. The humidity "softening" affected the outer corrugated boards. The type of damage that the high humidity and temperature pallets suffered was only compression set. The pallets at standard conditions saw both compression set and some creasing. The lack of creasing in high temperature and humidity pallets is most likely due to the greater flexibility or softening of the humid paper. Thus, instead of creasing, more compression was seen in these pallets.

Another study by Dennis (1995) investigated properties of corrugated pallets. The production of the cores is of vital importance to the compression strength for long term loading. The effects of the various damages to the cores during production were significant in relation to the compression strength. These faults caused premature failure of the damaged cores leading to lower values in comparison to the high quality samples.

This study also evaluated the safe stacking percentages derived from the average maximum dynamic load for constant loading test conditions. Based on these numbers, the "safe zone" included loads up to 54% of the maximum rating (Dennis, 1995). The loads, which exceeded this recommended guideline, had a high chance of failing during long- term storage.

It s important to keep in mind that the deck boards may deform at different rates due to localized loading. Pallets in service are subject to both static and dynamic (handling and transport) loads. Material type, pallet construction, loading and atmospheric conditions are all factors that may cause this deflection. Until now, a standard method for testing deflection of top deck during dynamic loads has not been found or used. In this study, the methods of testing and factors to consider for individual problems are discussed.

This study had the following objectives:

- To evaluate a test method "Beam Strength Deflection Test" developed by Stone Container to test the deck members of corrugated pallets.
- To compare the performance of C-flute corrugated board and Phoenixboard™ material for use in paper based pallets.
- To compare material properties of C-flute corrugated and Phoinixboard™ at normal and accelerated condition.

2.0 LITERATURE REVIEW

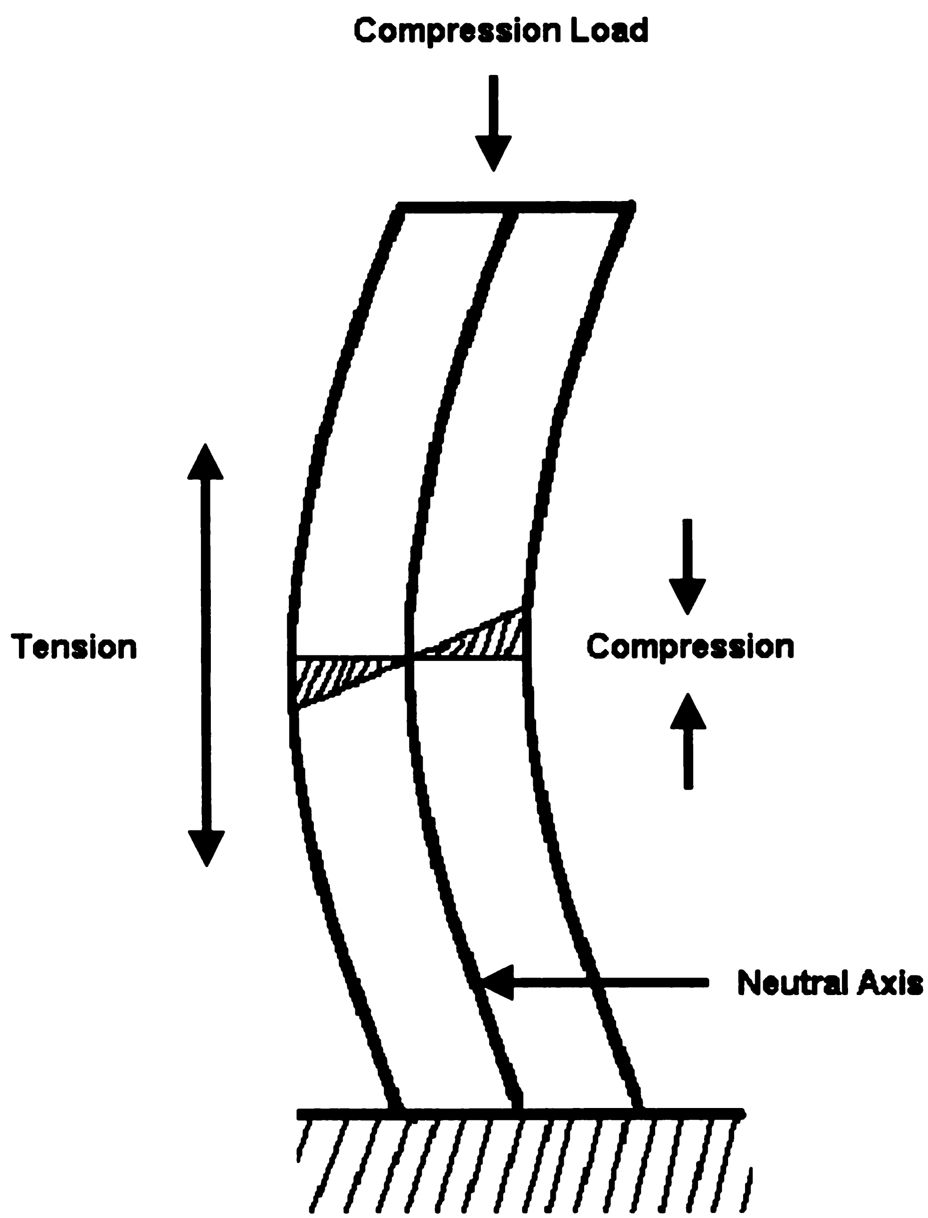
2.1 Board Structure and Strength

Fiberboard is composed of two structural components, the medium and the linerboard, which are combined with glue. These two components provide structural resistance to loading force. Liners are generally made of softwood fibers using the kraft pulping process and most of the mediums consist of recycled materials. The strength of the medium is very important to the overall strength of the board.

Since corrugated board is an "engineering structure," the object of optimizing is to make the structural characteristics work. The basic fact to remember is the way corrugated functions as a structure under load. When a corrugated column is under load, the structure bends until it buckles. Bending generates compression stresses in the inside liner, while the outside liner is in tension, as shown in Figure 1. Therefore, if the weights of inside and outside liners are balanced, the facing with the higher ring crush should be on the inside. By extension, if there is an unbalanced board combination, the heavier or the stiffer liner should be the inside liner (Maltenfort, 1988).

On double wall boards, there is an additional factor to be considered. The center liner is near the neutral axis where the compression contribution is minimal. Therefore, the optimum board combination is the one where the inside liner is the stiffest, the weakest liner is in the center, and the second stiffest liner is on the outside. The center liner needs only to be strong enough to hold the flute structure in place

FIGURE 1. Schematic of Stress in a Compressed Corrugated Panel



(Maltenfort,1988). The top-to-bottom compressive strength of regular slotted corrugated fiberboard containers can be predicted with reasonable accuracy from a compilation of the stress-strain properties of the facing and corrugating medium. It is more efficient to add fiber to the medium than to the linerboard when using 69 lbs. or heavier linerboard facing. Given paperboards of other stress-strain properties, it is possible that it may also be more efficient to add fiber to the medium than facing in lower weight grades. Boxes made with light weight facings and heavier corrugating mediums may actually have better top-to-bottom compressive strength than those made with heavier facings and light weight mediums (Koning, 1978).

Compression strength is related to various strength properties of the fiberboard. Sheet density and basis weight are related to board strength. The lower the sheet density, the lower the compression strength (Bristow et al, 1986). There are some measures which describe the strength of board: flexural stiffness, edge crush resistance, burst strength and puncture resistance. The effects of each will be discussed.

Flexural Stiffness

Flexural stiffness is the ability to resist bending of combined board. Differences in compression strength of corrugated boxes are mainly due to the difference in flexural stiffness of these constructions. This property depends primarily on the modulus of elasticity, caliper of the liners and the square of the combined board caliper. It is important to note that flexural stiffness depends on material properties and cross-section geometry. High flexural stiffness of corrugated board is achieved by using liners which have a high modulus of elasticity in tension and high caliper, and by maintaining as large a combined board caliper as possible. Conversion operations such as printing, which may decrease the combined board caliper through crushing, lower its potential stiffness (McKee et al, 1989).

The significance of flexural stiffness to top-load box compression strength is evident when comparing vertical-flute boxes fabricated from the same components in A-, B- and C-flute. The edgewise compression strengths of such boards are nearly equal. The small differences that appear may be attributable to the modest differences in amount of medium, number of glue lines, and other geometrical factors affecting the stability of the liners and flute side walls. The minor differences in edgewise compression strength between the several flute sizes do not account for the fact that the top-load box compression of A-flute boxes is greater than that of C-flute boxes of the same size and fabricated from identical components with the same degree of workmanship. The compression strength of C-flute boxes is, in turn, greater than for corresponding B-flute boxes (McKee et al, 1989). There are major differences in flexural stiffness for the several flute sizes because of the differing calipers of the combined board: A greater than C and similarly C greater than B. Thus, it is flexural stiffness, which accounts for the difference in the top-load compressive strength of A-, B- and C- flute boxes.

The bending stiffness is a very important factor for the stackability of the corrugated board. But there is still a lack of a reliable method to measure the binding stiffness. A higher basis weight of the fluting does not only increase the ECT values of corrugated board, but also ensures that the caliper of the corrugated board (and thereby the bending stiffness) is maintained during the converting. Caliper describes the stacking strength of the corrugated board as well as bending stiffness (Nordkvist, 1988).

Edge Crush Resistance

The edge crush resistance is the strength property most widely used to predict whole box compression strength. Today's environment box compression is the most important factor affection box performance. That is why the Edge Crush Test (ECT) for corrugated board is used to predict box strength. The ECT has been used as an index for the estimating the stackability of boxes stored on pallets in warehouses. The higher the edgewise compression resistance, the better the stacking properties of the boxes (Thielert, 1986).

There are many factors that influence the value of edge crush resistance. Choice of raw materials is an obvious parameter and it is the key variable. However, there are other factors under direct control in the box plant, such as adhesion and absence of crushing that influence the test results. Eriksson reported that a pin adhesion value of only 4 N/cm was required to reach an Edge Crush Test independent of adhesion strength (Eriksson, 1979). Thus, adhesion strength is of minimal importance in the ETC.

Glue skips are another factor. Increasing width of glue skip declines the ECT value modestly. A skip of 3mm can reduce the ECT by 5% (Kroeschell, 1992). In unpublished work, McKee reported that corrugated board with fractured flutes had a 15% reduction in ECT. Crushing also has a minimal effect on ECT. If C-flute corrugated board is crushed to the equivalent of B-flute, inducement of flexural failure and a significant reduction of ECT are expected. Batelka presented data which showed that this approximately 30% reduction in thickness resulted in a decrease of less than 15% in ECT (Batelka, 1984).

All of these variables, adhesion, and combined board thickness have only minimal effect on ECT, but linerboard and corrugated medium are very important components of ECT. ECT is a material property much more closely related to box strength than is bursting strength, and it is a test that recognizes the contribution of the corrugated medium to box performance. ECT was strongly related to the sum of the ring crush values of the component, facings and the medium in a unit length of combined board (Kroeschell, 1992).

While ECT is the single most important property of corrugated board in determining box compression strength, it is not the only factor by any means. The second important property is the board's flexural rigidity, and this is determined by the board's thickness.

Bursting Strength

The bursting strength, also referred to as Mullen, measures the containment capability of the board and therefore is influenced most by the strength of the liners. Burst strength does not relate directly with the box compression strength. Burst strength and basis weight are the two material properties of major concern in the manufacture of linerboard for corrugated fiberboard.

Mullen is practically independent of type of medium and flute construction. Since the contribution of the medium and flute structure to the total burst is small, the burst on the combined board is in effect a direct control on the quality of the liners used (Maltenfort, 1989). Bursting strength is a composite type of test. For example, it measures more than one property.

Mullen is a composite of tensile strength and stretch or elongation. The factors affection it are, according to TAPPI T 807, the proportion, type, preparation and the amount of fibers present in the sheet, their formation, internal sizing, and to some degree, the surface treatment (TAPPI T 807).

Puncture Resistance

The Puncture Test is a measure the total energy required to crush the board before it can be punctured (TAPPI 803 OM-88). The puncture strength of combined board cannot be readily estimated from a consideration of the puncture strength of the liners and corrugating medium because the design of the flute or flute geometry and the quality of the fabrication influence the combined board puncture (McKee, 1989).

Puncture is a better test for board quality than Mullen because it reflects the quality of medium as well as that of the liners, and it can be used to test triple wall which Mullen cannot (Maltenfort, 1989). The Puncture Test on combined board is dependent on the board design or flute geometry, the quality of the components and the quality of the fabrication. Consequently, the puncture test is sensitive to variation in flat crush, flute size, crushed or leaning flutes, degree of bonding, type of adhesive, etc. The liner is the dominant factor in the puncture test of combined board in terms of improving stiffness (McKee, 1989).

2.2 Corrugator Bonding

The gluing of medium to linerboard is probably the most critical operation in the manufacture of corrugated board. Corrugated board is manufactured in a two-step process. First, the medium is formed into the sinusoidal profile when it passes through a nip created by two gear-like rolls. Heat and moisture are applied to plasticize the medium. While the medium is still on one of the heated gear-like rolls, the adhesive is applied on the fluted tip and this, in turn, is immediately pressed against a preheated linerboard (Lepoutre et al, 1989).

The purpose of gluing is to achieve sufficient structural strength in the corrugated board. The structural strength is affected by process parameters, machine characteristics, the properties of paper and glue, and heat. Glueability is the ability of paper to anchor and to permit setting of the glue, which is determined by the glue's setting mechanism (Daub et al, 1990). The main parameters of the gluing process are the amount of glue applied, the joining pressure, heat, and the open time and closed time.

The quality of the bond between linerboard facing and the fluted medium is a critical factor in the performance of boxes made from corrugated board. Weak bond strength and defects such as blisters or loose edges adversely affect box performance and increase the box-plant's waste costs.

When two materials are glued together, the formation of a strong bond requires that the adhesive has good adhesion to the substrates and that it has adequate cohesive strength, preferably greater than that of either material. The requirement is that the adhesive wets the surface so intermolecular forces between the adhesive and the surface are established. The more chemically alike the two surfaces are, the stronger the intermolecular force and the stronger the bond achieved (Lepoutre et al, 1989).

2.3 Quality of Recycled Paperboard

During the 1960s, the retail revolution increased the demand for packaging board and corrugated packaging. This increased demand for packaging board made the industry expanded to meet the demand. The expansion was based largely on wastepaper use, so by the late 1970s, many paperboards were produced from wastepaper. But recycling alone, has many other problems.

When recycled fibers are used, it is inevitable that those lower strength properties such as Edge Crush Resistance, Burst Strength, Tensile Strength, etc, are reduced because of inter-fiber bonding. There are several mechanisms that reduce the inter-fiber bonding (McKinley, 1995).

- Recycled fines do not have adequate bonding properties and can act as an inert coarse filler, which interferes with inter-fiber bond formation.
- During the first cycle, fibers collapse without treatment during subsequent cycles, do not swell to their maximum potential, which reduces internal and external bonding.
- Hornification at the surface of the fiber, which increases stiffness so that fewer inter-fiber bonds will be formed, is due to reduced flexibility.
- Contaminants like clay, ink particles, stickies, chemicals, etc, may prevent inter-fiber bonding formation and may result in a localized weak points in the sheet.
- Some multivalent cations and salts may bond to carboxyl groups of fibers, which prevent inter-fiber bond formation. Inks and other additives may be sources of these interfering cations and salts.

Increased basis weight of recycled board will help provide the strength. By this method, recycled board can have strength equal to virgin grades. Use of strength aids is another general method to improve strength. Starch, the most widely used strength additive, improves inter-fiber bonding through adsorption and the creation of new bonding sites on fiber surfaces with stronger than original fiber-to-fiber bonds (McKinley, 1995).

With recycled grads, inter-fiber bonding can be improved by sheet densification through increased wet pressing, or by refining of the layers. Since the caliper of recycled board, at equivalent basis weights, is usually lower than virgin pulp board, stiffness tends to be lower. However, stiffness is not just a function of caliper. It is also related to fiber bonding and fiber stiffness. Fiber bonding improves with refining and although caliper falls, stiffness increases (Estes, 1986). Use of higher grades of fiber like softwood in corrugating medium production is another alternative.

Most corrugated medium is produced from 100% wastepaper in Europe. Initially, wastepaper grades consisted of clippings but this material was replaced by old corrugated containers to reduce costs. Most of the waste-based fluting produced is in the lower weight grades. When recycled mediums are compared with virgin, they are usually weaker, with lower caliper and hence lower stiffness. Stiffness of recycled mediums can be as low as 50% of those of virgin mediums and properties are variable due to an inability to control the fiber blend exactly, as well as the tendency that residual contaminants give localized weak spots in the medium (McKinley, 1995).

Waste-based flutings are normally lower in price than virgin, which will influence the choice of use. But quality of the materials is also important factor. Type of fluting should be considered complementary since there are many circumstances in which wasted-based performance, especially lower weight grades, is acceptable. Providing a higher weight recycled grade except when high performance is required can compensate for poor performance of recycled mediums at equivalent basis weights.

Recycled linerboard made from 100% wastepaper does not meet original Burst Strength standards. When liner was made from clean OCC (Old Corrugated Container) and post-consumer OCC and then compared with virgin kraft liner, the burst strength of the clean OCC was 22% lower and contamination was 50% lower. Ring crush of the clean OCC was only a few percent lower than kraft liner, but the post-consumer was almost 20% lower in RCT (Fahey et al, 1982). Kraft liner at equivalent basis weight to recycled liner has a better bending stiffness and higher resistance to creasing and cracking, as well as giving higher case compressive strengths at high humidities (Martin, 1989).

The internal strength of recycled liner also tends to be lower, which can cause weaknesses at glue joints in the corrugating case, leading to case failure. It is improved by refining, by chemical use, high-intensity wet pressing, wastepaper grade selection, etc. (McKinley, 1995).

Recycled liner boards tend to have lower coefficients of friction than kraft, due to the much greater use of wax to control moisture resistance of containers. Wax is not the only material to reduce the angle of slip. Residual fatty acids or other pulp extractives also have some affect (Gunderson, 1993). Surface roughness is not a factor in increasing friction. Friction increases proportionally with the increased moisture content of the board (Inoue et al, 1990).

Recently a new material has been developed by Fortifiber Corporation. This material called "Phoenixboard™" is manufactured using 100 % recycled materials. The process involves sandwiching a filler made of 100 % recycled and crushed laminated PE/paperboard cartons in two layer of 100 % recycled paper. The bonding process occurs as this sandwiched material is pressed between heated rollers which melt the PE and fuse the material together. "Phoenixboard^{TM}" is currently being used as a separator sheet or slip sheet for shipping rolls of paper and aluminum. This study was functionality of "Phoenixboard^{TM}" to be used for top and bottom decks of corrugated pallets.

3.0 EXPERIMENTAL DESIGN

In order to accomplish the objectives of this study, Six different tests were conducted: the Membrane Stretch, Edge Crust, Burst Strength, Puncture Friction and Moisture Absorption tests. The individual test materials, conditions and methods used for each experiment are discussed in this chapter.

3.1 Test Materials

Phoenixboard™, manufactured by the Fortifiber Corporation was used for this experiment. This board uses a 100% recycled liners. The medium consists of industrial waste obtained from the die-cut trimming of paperboard cartons that use a polyethylene laminate (e.g. milk carton blanks). The shredded medium is bonded between the two liners using high pressure and heated rollers. By modifying the consistency of the medium, the thickness of the board can be altered depending on the situation and the requirements demanded. In this experiment, four different thicknesses were tested: 60 pt, 80 pt, 100pt and 110 pt. C- flute single wall corrugated board was tested to serve as a comparison to the Phoenixboard™. Each test required different sizes of materials as shown below.

Basic weight of Phoenixboard™ (100 pt.): 1.1880g / in^2

Basic weight of C-flute corrugated board: 0.3968g / in^2

Sheet size:

24″ × 24″ for Membrane Stretch test

12″ × 12″ for Puncture and Burst test

5″ × 8″ for Friction test

2″ × $1^1/_4$″ for Edge Crush test

5″ × 5″ for moisture absorption test

3.2 Apparatus

The following equipment was used to conduct the each test.

1. Membrane Stretch test

   Lansmont compression tester

   PVC Tubing

   Wood frame (see Figure4)

2. Edge Crush test

   Standard sample cutter

   TMI crush tester

3. Burst test

   Mullen burst tester

4. Puncture test

   Beach Puncture tester (with weight "A")

5. Friction test

   MTS T-5000 tensile tester

3.3 Test Conditions

The materials were conditioned using the ASTM (American Society for Testing and Materials) D-4332 "Standard Practice for Conditioning Containers, Packages, or Packaging Components for Testing". For the Beam Strength Deflection test, a tropical condition of 100°F and 85% RH was selected and the materials were conditioned for 24 hours.

For the other tests, two simulated warehouse atmospheric conditions for this experiment were used: standard (70°F, 50%RH) and tropical (100°F, 85%RH). Materials were stored separately for 72 hours in each selected condition. The temperatures and humidity for the standard and tropical condition were consistent with the recommendations of ASTM D 4332.

3.4 Test Method

- **Membrane Stretch Test**

This test method was designed to simulate the load deflection of the top or bottom decks between the blocks of corrugated pallet. The mechanism used for this experiment is shown in Figure 2.

The PVC tubing is held to the upper part of the compression tester by clamps. Also, the materials under the force of the compression tester are held in the wooden frame by clamps. The wooden frame is placed in the moving part of the compression tester. This wooden fixture is used to hold a 24″ × 24″ sheet of corrugated material between two clamps $12^1/_4$ inch apart. The PVC tubing which is attached to the upper part of compression tester applies the compression pressure to the center of the sheet.

FIGURE 2. MEMBRANE STRETCH TESTER

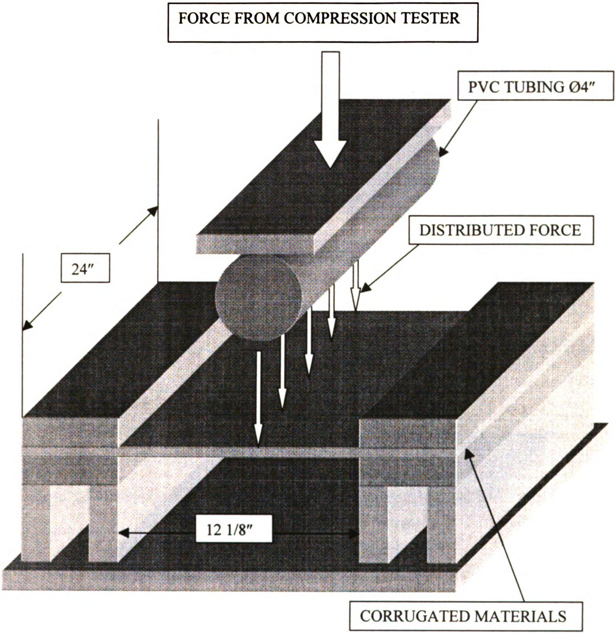
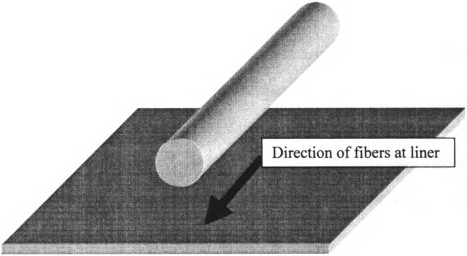
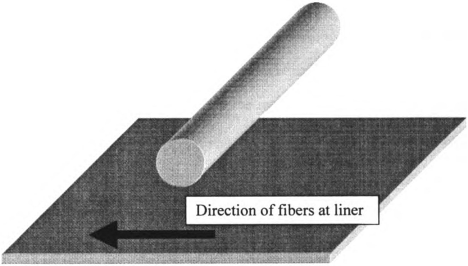


FIGURE 3. MACHINE AND CROSS DIRECTION



MACHINE DIRECTION



CROSS DIRECTION

As the load increased, the pressure (in pounds) is recorded at $^1/_4$ inch deflection intervals up to 1 inch. Five samples of each material were tested at cross and machine direction. Four different thicknesses were used in this experiment.

- **Edge Crush Test**

The Edge Crush test of corrugated boards is defined as the force per unit length of the specimen that is required to crush the corrugated board when it is pressed together in the direction parallel to the flutes. This test method determines the edgewise compressive strength of corrugated fiberboard. The edge crush values for the pre-conditioned specimens were determined by the test procedure outlined in ASTM D2808-69.

In the ECT, a rectangular (2″ × $1^1/_4$″) specimen of corrugated board is placed on its edge in a compression tester. The sample is placed between the platens by use of the two supporting blocks which hold the sample upright.

The largest force which the specimen will support without being crushed, is reported as the edge crush value. Both liners and medium are stressed in a uniform manner. The load is applied perpendicular to the flutes. Samples must be prepared with extreme caution and care. Uneven cuts will result in relatively low test values that do not reflect the actual strength of the product. Six specimens of each board type were tested under both standard and tropical conditions.

- **Bursting Strength Test**

The burst strength test provides the bursting strength of corrugated board and solid fiberboard. The procedure is described in ASTM D2738-71 (or TAPPI T 810 om-85).

In this test, the material is secured between platens and is ruptured by an expanding rubber diaphragm. The pressure from the diaphragm rises until the specimen ruptures. The clamp pressure is the main variable that influences the test results. The clamping pressure must be sufficient so that the board cannot slip during the test, but at the same time the pressure should not crush the board. Bursting pressure should be turned off immediately after rupture by putting the lever in reverse.

- **Puncture Test**

This test is performed to provide data concerning the puncture resistance of paperboard, corrugated and solid fiberboard. The procedure followed the steps described in TAPPI 803 om-88.

The Puncture Resistance test is a measurement of the resistance of board to be punctured. The energy required to puncture the board is a combination of the energy to tear the board and the energy to bend the material out of the way at the puncture. The Puncture test is defined as the biggest force that is applied to puncture the board.

The test material is placed in the tester and the clamping jaws are separated. The collar on the pendulum is pushed up towards the head. After the pendulum punches the board by releasing the latch, the pendulum should be held to prevent from swinging back. The pointer should stop inside the scale to read the measurement. If not, the weight on the apparatus should be changed to be heavier.

- **Friction Test**

This test method determines the ability of a package to hold on pallet or in a stack, which is one of the most critical properties of a package during distribution. The friction values for this experimental activity were determined by methods of TAPPI 503 standard.

The specimens are clamped on the horizontal plane and sled. The sled is placed onto the horizontal plane and will be moved to some desired position on the horizontal plane. That position of angle is recorded.

- **Moisture Absorption Test**

60 pt., 80 pt. and100 pt. Phoenixboard™ and C-flute corrugated boards are used in this test. Five of each samples are weighted separately and put in the water for two minutes. The wet materials are carefully weighted. Difference of the weight is recorded for moisture absorption.

4.0 DATA AND RESULTS

Six different experiments were conducted to test for the durability and performance of paper based pallets. The data collected and the results of these experiments are discussed in this chapter.

4.1 Membrane Stretch Test

The raw data for machine and cross direction of the Phoenixboard™ are presented in Tables 1 and 2. The load (in pounds) was recorded at $^1/_4$ inch deflection intervals up to 1 inch for each varying thickness of the board. This was deformed under compression but did not fail until the compression tester reached 1 inch deflection. This value will be positive representing the performance of this material used for top deck of corrugated pallets. The positive performance of this material indicates that high temperature and humidity have no significant effects on the performance of the pallets because these materials were conditioned in the humidity chamber before they were tested.

Table 3 shows the data of the C-flute corrugated board for both directions. This will serve as the standard of the paper based pallet to compare with the performance of Phoenixboard™. In this case, the corrugated boards were too weak to endure the same test as Phoenixboard™. Corrugated boards failed before the boards reached 1 inch deflection and the peak force was recorded in pounds as a failure.

Comparing the numerical values of these two materials, the corrugated board can endure a higher force at the same deflection before it fails than the Phoenixboard™ can. This result, however, does not mean that the corrugated board has a higher endurance level than the Phoenixboard™. The Phoenixboard™ is more flexible than corrugated and this can withstand a higher compression load.

Deflection strength properties of paper based board is related to its structural components. The density of the medium is an especially important factor. Density of the board is directly proportional to its compression strength.

This material, which is filled with recycled carton between liners, has a high density. The corrugated board, however, has only a fluted medium between its liners with a low density that cannot support deflection effectively. This structural difference makes the Phoenixboard™ superior because of its ability to withstand high loads at high deflection.

4.2 Other Test

Tables 4 to 9 show the results of these four experiments: Bursting Strength test, Puncture Strength test, Edge Crush test and Friction test. Table 9 shows all data for the corrugated board used in the four tests. These four experimental tests are designed to determine the strength properties and functional abilities of paper boards.

From the results of the tests, the Phoenixboard™ appears to possess properties similar to corrugated board. These properties are very important factors determining the strength of paper board. But when used as a top or bottom deck of the pallet, these factors do not significantly affect the performance of the pallet.

Table 4 shows the results of Edge Crush test of the Phoenixboard™. Results for the corrugated board are presented in Table 9. Both boards exhibited higher values when they were controlled in a standard condition than an accelerated condition. The time of the experiment (morning, afternoon and evening) and the result of the experiment do not appear to have any relationship. This result defines the structure of the medium since the recycled carton of the Phoenixboard™ is not affected severely under the different conditions. C-flute corrugated board has higher value than 60pt. and 80 pt. but has lower value than 100 pt. C-flute also has light weight advantage. The Edge Crush values are related with core (legs) of the paper-based pallet. Higher value of the ECT value can endure the heavier load as a core of the pallet. By these reasons, C-flute corrugated board is effected for core of the pallet more than Phoenix board.

Table 5 shows the results of Burst Strength test for the Phoenixboard™. In this case, the corrugated board (Table 9) has a much higher value than the Phoenixboard™. This discrepancy is attributed to the fact that the medium of the Phoenixboard™ does not support adequately to prevent the burst of the liner and the bursting strength is influenced most by the strength of the liners. Therefore, this material has weaker liners than the corrugated. This test also shows that the Phoenixboard™ has higher values at standard conditions than corrugated and does not have a relationship to different test times.

Results of the Puncture test are presented in Table 8. The unit of measure for this test is BPU (Beach Puncture Unit). Both materials have similar punctual resistance strengths. Puncture strength is dependent on the quality of the individual components, flute geometry, board design and fabrication quality. The liner is the dominant factor in the puncture test. For Phoenixboard™, the solid high density medium material helps the weaker liner withstand the test despite of weak liner.

The puncture and burst tests may provide information about resistance of top deck which is impacted from dropping of small packages such as cans, bottles, etc. 60 and 80 pt. of Phoenixboard™ have lower values than C-flute corrugated but 100pt.has higher value. Suitable board will be used at variable handling and transportation situation.

Table 9 shows the results of Friction test. This test shows the slippery surface characteristics between the top deck and first layer of boxes. The unit used for this test is the Coefficient of Friction. The data reveals the higher friction value of the corrugated board, which indicates that the Phoenix board is more slippery than the corrugated board. Most of case, the recycled materials have lower friction value. This friction value is not significantly affected by change of humidity conditions.

Table 10 represents the data for moisture absorption for phoenixboard™ and C-flute corrugated board. C-flute corrugated board absorb more moisture than Phoenixboard™. 60 pt. board absorbs least. So this board will be most suitable board for bottom deck of paper-based pallets because bottom deck will be effected by water on the storage floor. This is very important factor for paper-based pallet.

TABLE 1. MEMBRANE STRETCH TEST OF PHOENIXBOARD (MACHINE DIRECTION) (lbs.)

Thickness	Number	0.25 in.	0.50 in.	0.75 in.	1.00 in.
60 (pt)	1	6.00	15.00	30.00	54.00
	2	4.00	9.00	18.00	34.00
	3	4.00	12.00	24.00	46.00
	4	4.00	12.00	24.00	50.00
	5	6.00	10.00	25.00	45.00
	Ave.	4.80	11.60	24.20	45.80
	Std.Dev	1.09	2.30	4.27	7.49
80 (pt)	1	4.00	10.00	19.00	36.00
	2	7.00	16.00	30.00	53.00
	3	6.00	13.00	27.00	46.00
	4	6.00	15.00	26.00	46.00
	5	6.00	13.00	24.00	42.00
	Ave.	5.80	13.40	25.20	44.60
	Std.Dev	1.09	2.30	4.08	6.22
100 (pt)	1	9.00	17.00	31.00	51.00
	2	6.00	10.00	21.00	37.00
	3	6.00	15.00	27.00	45.00
	4	8.00	16.00	30.00	50.00
	5	10.00	19.00	36.00	57.00
	Ave.	7.80	15.40	29.00	48.00
	Std.Dev	1.78	3.36	5.52	7.48
110 (pt)	1	7.00	16.00	33.00	59.00
	2	6.00	15.00	27.00	48.00
	3	7.00	16.00	31.00	54.00
	4	7.00	16.00	31.00	54.00
	5	6.00	16.00	28.00	51.00
	Ave.	6.60	15.80	30.00	53.20
	Std.Dev	0.54	0.44	2.44	4.08

TABLE 2. MEMBRANE STRETCH TEST OF PHOENIXBOARD (CROSS DIRECTION) (lbs.)

Thickness	Number	0.25 in.	0.50 in.	0.75 in.	1.00 in.
60 (pt)	1	9:00	21.00	37.00	63.00
	2	10.00	22.00	42.00	59.00
	3	10.00	21.00	33.00	53.00
	4	9.00	19.00	34.00	54.00
	5	11.00	21.00	34.00	54.00
	Ave.	9.80	20.80	36.00	56.60
	Std.Dev	0.83	1.09	3.67	4.27
80 (pt)	1	13.00	28.00	39.00	57.00
	2	7.00	16.00	30.00	53.00
	3	15.00	30.00	45.00	63.00
	4	15.00	28.00	39.00	59.00
	5	16.00	33.00	43.00	60.00
	Ave.	13.20	27.00	39.20	58.40
	Std.Dev	3.63	6.48	5.76	3.71
100 (pt)	1	16.00	33.00	43.00	62.00
	2	16.00	33.00	46.00	63.00
	3	15.00	30.00	42.00	63.00
	4	18.00	34.00	46.00	63.00
	5	16.00	34.00	51.00	65.00
	Ave.	16.20	32.80	45.60	63.25
	Std.Dev	1.09	1.64	3.50	1.09
110 (pt)	1	18.00	36.00	50.00	65.00
	2	22.00	42.00	53.00	65.00
	3	19.00	33.00	50.00	68.00
	4	16.00	31.00	43.00	62.00
	5	21.00	40.00	53.00	66.00
	Ave.	19.20	36.40	49.80	65.20
	Std.Dev	2.38	4.61	4.08	2.16

TABLE 3. MEMBRANE STRETCH TEST OF C-FLUTE CORRUGATED BOARD

		0.25 in.	0.50 in.	0.75 in.	1.00 in.	Failure
MACHINE DIRECTION	1	32 lbs.	-	-	-	34
	2	34	-	-	-	36
	3	37	-	-	-	39
	4	35	-	-	-	37
	5	34	-	-	-	36
	Ave	34.4	-	-	-	36.4
	Std.	1.82	-	-	-	1.82
CROSS DIRECTION	1	30	46	59	-	60
	2	25	45	-	-	51
	3	27	43	59	-	60
	4	27	45	58	-	59
	5	29	46	60	-	62
	Ave	27.6	45	59	-	58.4
	Std.	1.95	1.22	0.82	-	4.28

TABLE 4. EDGE CRUSH TEST OF PHOENIXBOARD
(lbs./in)

THICKNESS	RUN		STD	ACCL
60 (pt)	1	Avg.	14.6	10.9
		Std. Dev.	1.0	1.8
	2	Avg.	17.4	15.4
		Std. Dev.	2.5	0.5
	3	Avg.	11.3	12.8
		Std. Dev.	3.0	2.7
80 (pt)	1	Avg.	12.6	14.2
		Std. Dev.	2.4	3.3
	2	Avg.	21.7	14.5
		Std. Dev.	4.8	3.0
	3	Avg.	23.8	13.3
		Std. Dev.	3.5	1.3
100 (pt)	1	Avg.	49.8	45.7
		Std. Dev.	14.2	15.7
	2	Avg.	22.8	24.2
		Std. Dev.	1.1	6.0
	3	Avg.	21.8	19.6
		Std. Dev.	24.5	26.3

TABLE 5. BURST TEST OF PHOENIXBOARD
(psi)

THICKNESS	RUN		STD	ACCL
60 (pt)	1	Avg.	124.3	115.0
		Std. Dev.	7.1	5.0
	2	Avg.	199.3	208.3
		Std. Dev.	24.0	20.8
	3	Avg.	118.7	113.3
		Std. Dev.	1.5	7.6
80 (pt)	1	Avg.	116.7	103.7
		Std. Dev.	7.6	1.5
	2	Avg.	125.0	112.7
		Std. Dev.	15.0	3.1
	3	Avg.	138.3	130.7
		Std. Dev.	16.1	4.0
100 (pt)	1	Avg.	151.7	155.0
		Std. Dev.	16.1	20.0
	2	Avg.	216.7	194.0
		Std. Dev.	14.4	28.7
	3	Avg.	134.3	143.3
		Std. Dev.	37.8	32.4

TABLE 6. PUNCTURE TEST OF PHOENIXBOARD (BPU)

THICKNESS	RUN		STD	ACCL
60 (pt)	1	Avg.	226.7	255.0
		Std. Dev.	23.6	5.0
	2	Avg.	280.0	361.7
		Std. Dev.	5.0	12.6
	3	Avg.	241.7	315.0
		Std. Dev.	12.6	25.0
80 (pt)	1	Avg.	226.7	278.3
		Std. Dev.	7.6	12.6
	2	Avg.	281.7	360.0
		Std. Dev.	7.6	15.0
	3	Avg.	265.0	310.0
		Std. Dev.	13.2	15.0
100 (pt)	1	Avg.	381.7	450.0
		Std. Dev.	16.1	25.0
	2	Avg.	423.3	350.0
		Std. Dev.	22.5	25.0
	3	Avg.	405.5	357.7
		Std. Dev.	68.0	56.3

TABLE 7. FRICTION TEST OF PHOENIXBOARD
(coefficient of friction)

THICKNESS	RUN		STD	ACCL
60 (pt)	1	Avg.	0.26	0.22
		Std. Dev.	1.0	0.6
	2	Avg.	0.25	0.21
		Std. Dev.	1.0	1.7
	3	Avg.	0.25	0.23
		Std. Dev.	1.7	2.0
80 (pt)	1	Avg.	0.25	0.21
		Std. Dev.	0.0	2.1
	2	Avg.	0.23	0.25
		Std. Dev.	0.0	0.0
	3	Avg.	0.23	0.21
		Std. Dev.	0.0	0.6
100 (pt)	1	Avg.	0.26	0.23
		Std. Dev.	0.6	0.0
	2	Avg.	0.2	0.20
		Std. Dev.	1.5	0.6
	3	Avg.	0.24	0.24
		Std. Dev.	1.0	1.1

TABLE 8. MATERIAL PROPERTIES OF PHOENIXBOARD

TEST METHOD	BOARD THICKNESS (pt)					
	60		80		100	
	STD	ACCL	STD	ACCL	STD	ACCL
Bursting Strength (psi)	147.44	145.56	126.67	115.67	167.56	164.11
Puncture Strength (BPU)	249.44	310.56	257.78	316.11	403.33	385.89
Edge Crush (lbs/in)	14.39	13.02	19.34	14.00	31.44	29.79
Coefficient of Friction	0.25	0.22	0.24	0.22	0.25	0.24

TABLE 9. MATERIAL PROPERTY TEST FOR C-FLUTE CORRUGATED BOARD

TEST		STD	ACCL
BURST TEST (psi)	1	245	247
	2	258	267
	3	295	229
	Avg.	266.0	247.6
	Std.Dev	25.9	19.0
PUNCTURE TEST (BPU)	1	374	368
	2	386	367
	3	382	369
	Avg.	380.6	368.0
	Std.Dev	16.1	1.0
ECT TEST (lbs/in)	1	27.9	25.4
	2	29.8	27.5
	3	28.8	27.9
	4	29.5	27.1
	5	27.8	27.4
	6	28.4	26.3
	Avg.	28.7	26.9
	Std.Dev	0.8	0.9
FRICTION TEST (Coefficient of Friction)	1	0.53	0.52
	2	0.61	0.48
	3	0.56	0.53
	Avg.	0.57	0.51
	Std.Dev	0.04	0.03

TABLE 10. MOISTURE ABSORPTION TEST

	C-flute	60 pt.	80 pt.	100 pt.
1	9.5477 g	5.7647 g	6.5891 g	6.0444 g
2	9.6333 g	4.9777 g	7.3939 g	7.6693 g
3	9.4238 g	4.7773 g	7.6905 g	6.9755 g
4	9.0331 g	4.4974 g	5.7250 g	6.4461 g
5	8.9873 g	4.4097 g	6.9362 g	7.2443 g
Avg.	9.3250 g	4.8853 g	6.8869 g	6.8759 g
Std.Dev.	0.2973	0.5408	0.7651	0.6425

5.0 CONCLUSIONS

Paper based pallets are cost effective and environmentally friendly to transport a variety of products. The pallet material used in this experimental study, Phoenixboard™ can withstand heavier loads when used as top decks for paper based pallets. This material can withstand higher loads when compared to C-flute corrugated for deflections up to 1 inch. The 1 inch deflection represents the maximum limit of deformation of the top deck that still permits access to material handling equipment such as fork trucks and pallet jacks.

The test method used in this study is truly producing a lateral tension in the material (stretching) and therefore the title for this test has been modified from "beam Strength Deflection Test" to "Membrane Stretch Test".

The material property tests traditionally used for corrugated board box performance such as Burst Strength, Puncture Resistance, ECT and Friction do not reflect performance of pallet decks. However the ECT is a good test to evaluate the compression resistance of pallet cores or blocks.

An ideal pallet should have blocks made from paper corrugated and decks made from Phoenixboard™ to have superior performance.

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